

# What does a Higgs boson eat during the winter ...and other essential details

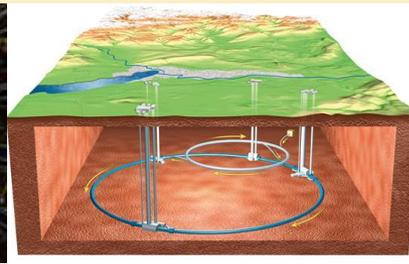
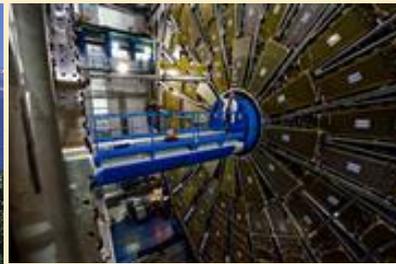
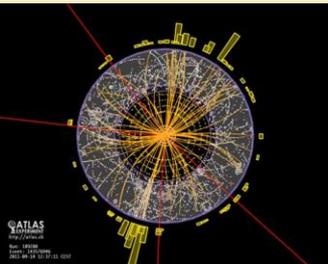


**Pauline Gagnon, CERN et Indiana University**  
**Physicist on ATLAS experiment and communicator**

# CERN

- # **European Laboratory for Particle Physics**
- # 12000 scientists of 99 different nationalities
- # Financed by European countries
- # Many other countries participate in various projects  
Canada, United States, Japan, Israel, India, Pakistan etc.

# **Common goal: find out what matter is made of**

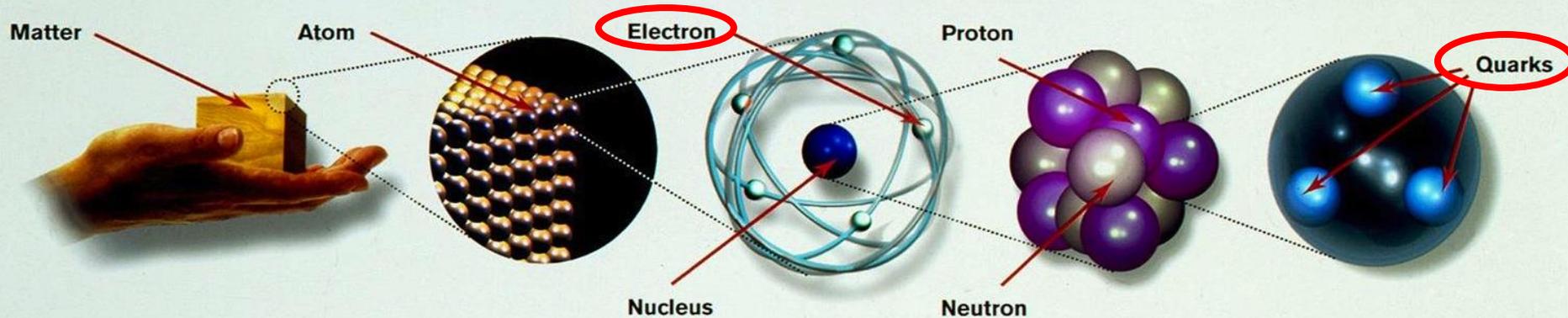


# The Legoland version of Copenhagen





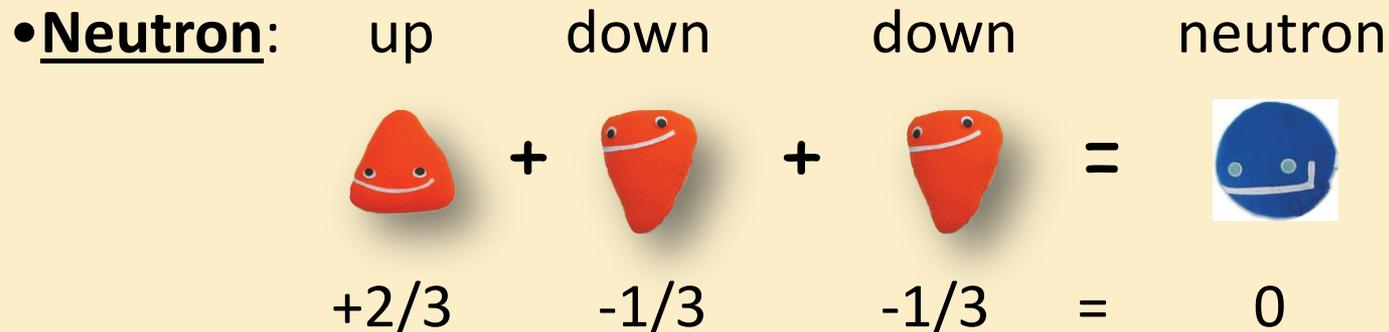
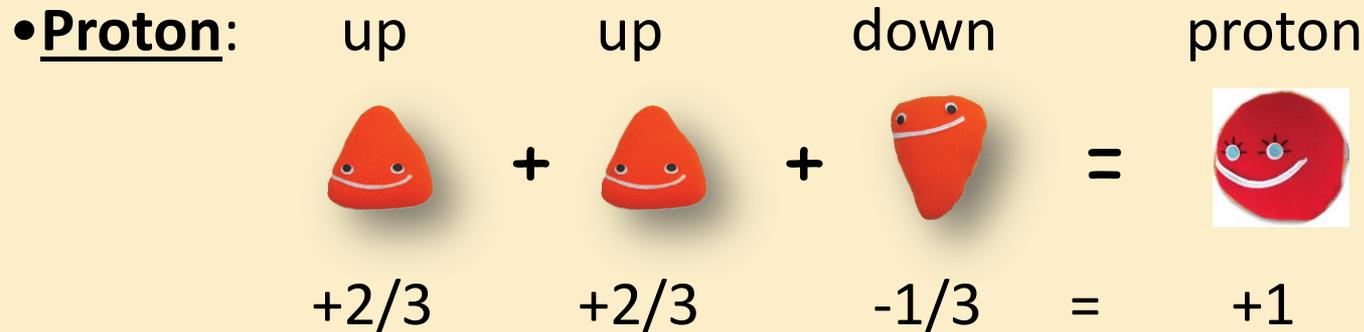
# What are the smallest building blocks of matter?



**The only fundamental particles here  
are electrons and quarks**

# Protons and neutrons are made of quarks

**Up :**  (charge  $+2/3$ ) and **down quarks:**  (charge  $-1/3$ )



# That's all you need to form all elements

Metals										Nonmetals									
Alkali metals										Other nonmetals									
Alkaline earth metals										Noble gases									
Lanthanoids										Transition metals									
Actinoids										Poor metals									
1 <b>H</b> Hydrogen 1.00794	Atomic # Name Symbol Atomic Mass																		2 <b>He</b> Helium 4.002602
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182																	10 <b>Ne</b> Neon 20.1797	
11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.3050																	18 <b>Ar</b> Argon 39.948	
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.64	33 <b>As</b> Arsenic 74.92160	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798		
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (97.9072)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.90550	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.710	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.60	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293		
55 <b>Cs</b> Caesium 132.9054519	56 <b>Ba</b> Barium 137.327	57-71																86 <b>Rn</b> Radon (222.0176)	
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89-103																118 <b>Uuo</b> Ununoctium (294)	
72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.98040	84 <b>Po</b> Polonium (208.9824)	85 <b>At</b> Astatine (209.9871)	86 <b>Rn</b> Radon (222.0176)					
104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (262)	106 <b>Sg</b> Seaborgium (266)	107 <b>Bh</b> Bohrium (264)	108 <b>Hs</b> Hassium (277)	109 <b>Mt</b> Meitnerium (268)	110 <b>Ds</b> Darmstadtium (271)	111 <b>Rg</b> Roentgenium (272)	112 <b>Uub</b> Ununbium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Uuq</b> Ununquadium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Uuh</b> Ununhexium (292)	117 <b>Uus</b> Ununseptium	118 <b>Uuo</b> Ununoctium (294)					

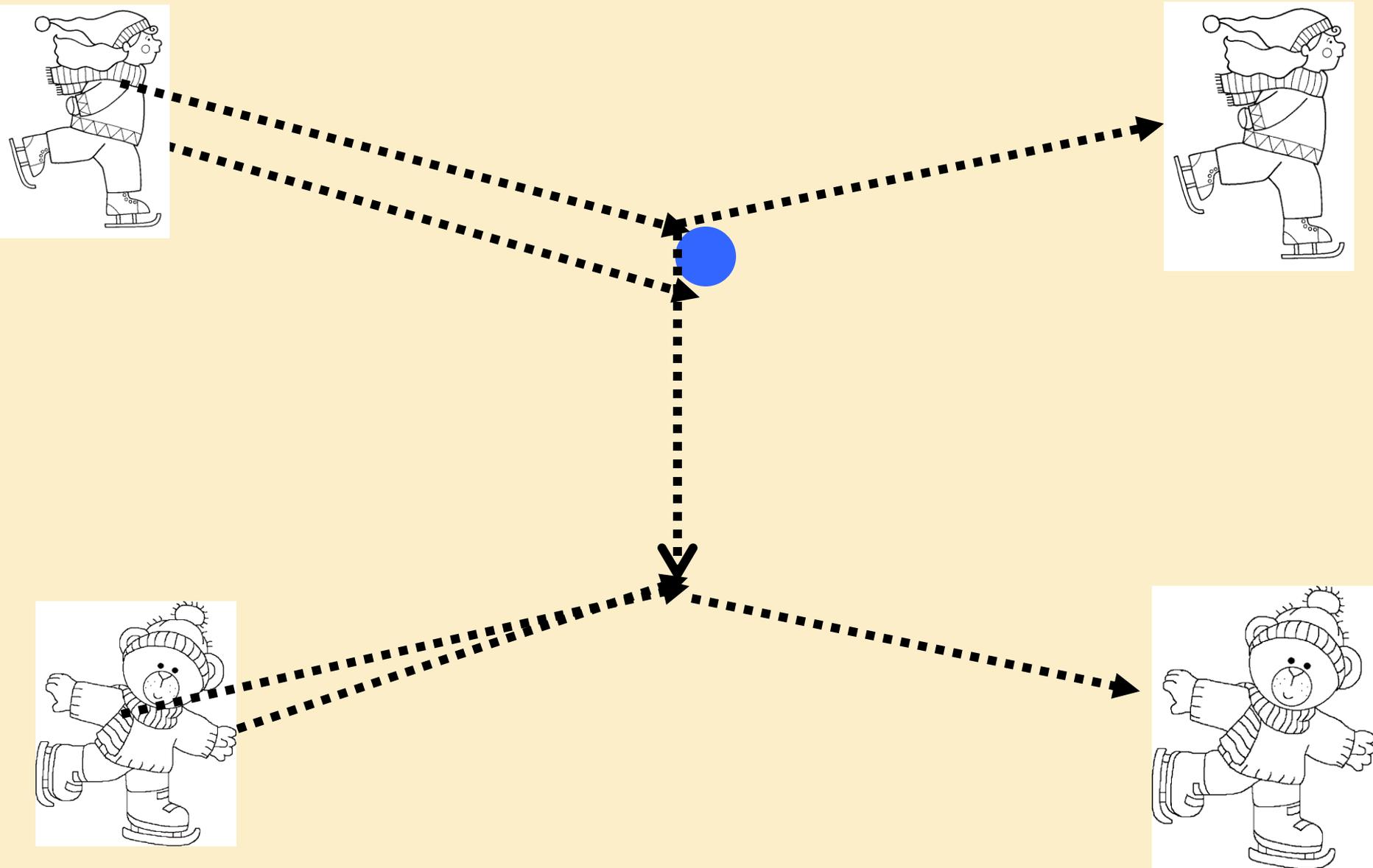
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90785	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.500	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9688
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03588	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

# Particles interact by exchanging other particles



# The Standard Model

1. All matter is made of fundamental particles

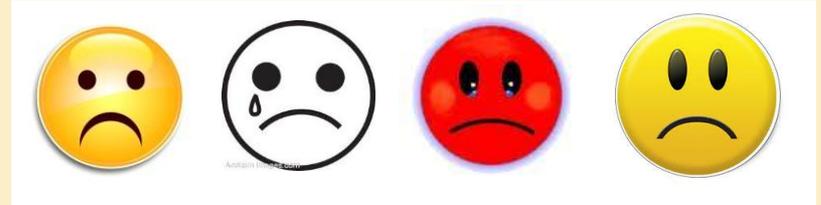
	LEPTONS			QUARKS		
Ordinary matter	ELECTRON 	ELECTRON NEUTRINO 		UP 	DOWN 	
	MUON 	MUON NEUTRINO 		CHARM 	STRANGE 	
	TAU 	TAU NEUTRINO 		TOP 	BOTTOM 	

2. Exchange particles called **bosons** are associated to forces

GLUONS  <i>Strong interaction</i>	PHOTONS  <i>Electromagnetism</i>	W and Z BOSONS  <i>Weak interaction</i>	GRAVITONS  ? <i>Gravitation</i>	HIGGS  <i>Brout-Englert-Higgs field</i>
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# Major problem with the equations

- The Standard Model only predicted massless particles



- But we knew that the  $W^+$ ,  $W^-$  and  $Z^0$  bosons had a mass



massless photon +



massive bosons

**How could the equations of the Standard Model generate massive particles?**

# Modify the equations of the Standard Model

In 1964, several theorists proposed a mechanism that would explain how particles could acquire mass



Tom Kibble, Gerald Guralnik, Carl Hagen, François Englert, Robert Brout, Peter Higgs

# To generate mass, we need:

## 1. The Brout-Englert-Higgs mechanism

- A mathematical description

## 2. The Higgs field

- A real physical entity corresponding to this mechanism

## 3. The Higgs boson

- The materialisation or proof of existence of all that

# 1. The Brout-Englert-Higgs mechanism

Theory predicted 4 massless bosons



The Brout-Englert-Higgs mechanism breaks this symmetry by remixing everything after injecting 3 fictitious particles



	Mass in GeV	Electric charge
photon	0	0
$W^+$	80.4 GeV	+1
$W^-$	80.4 GeV	-1
$Z^0$	91.2 GeV	0

- Mass

In physics, mass is  
*resistance to movement*

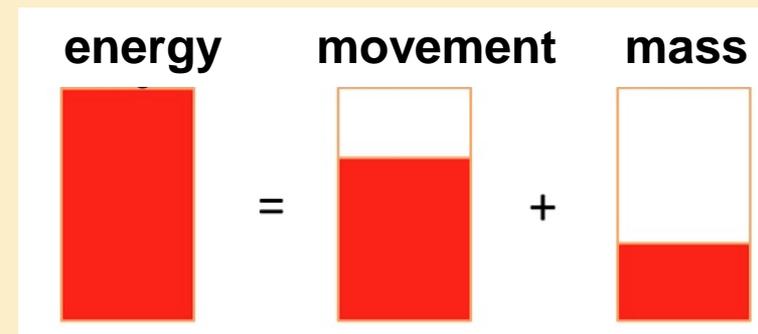


- $E = m c^2$

Energy and Mass are  
equivalent

- Energy conservation

Energy can take several forms  
but its sum is always conserved



## 2. The Higgs field

- # Running on the beach, light and free like air
- # Then running in water
- # You get the impression of getting sluggish



**With the Higgs field, it is as if the whole space is viscous**

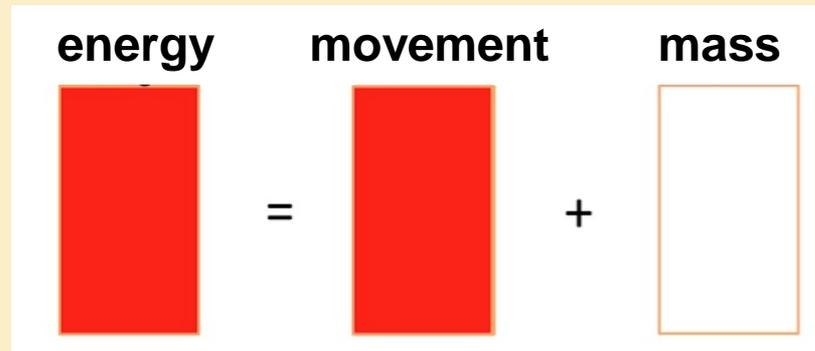
## 2. How does the Higgs field generate mass

A



Empty space, without a Higgs field

B

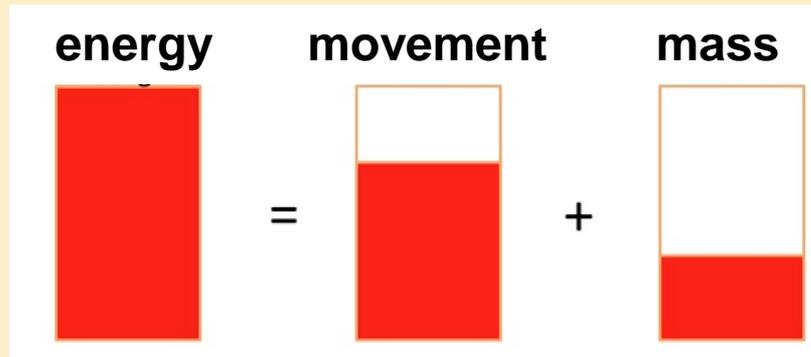


# Space with the Higgs field

A



B



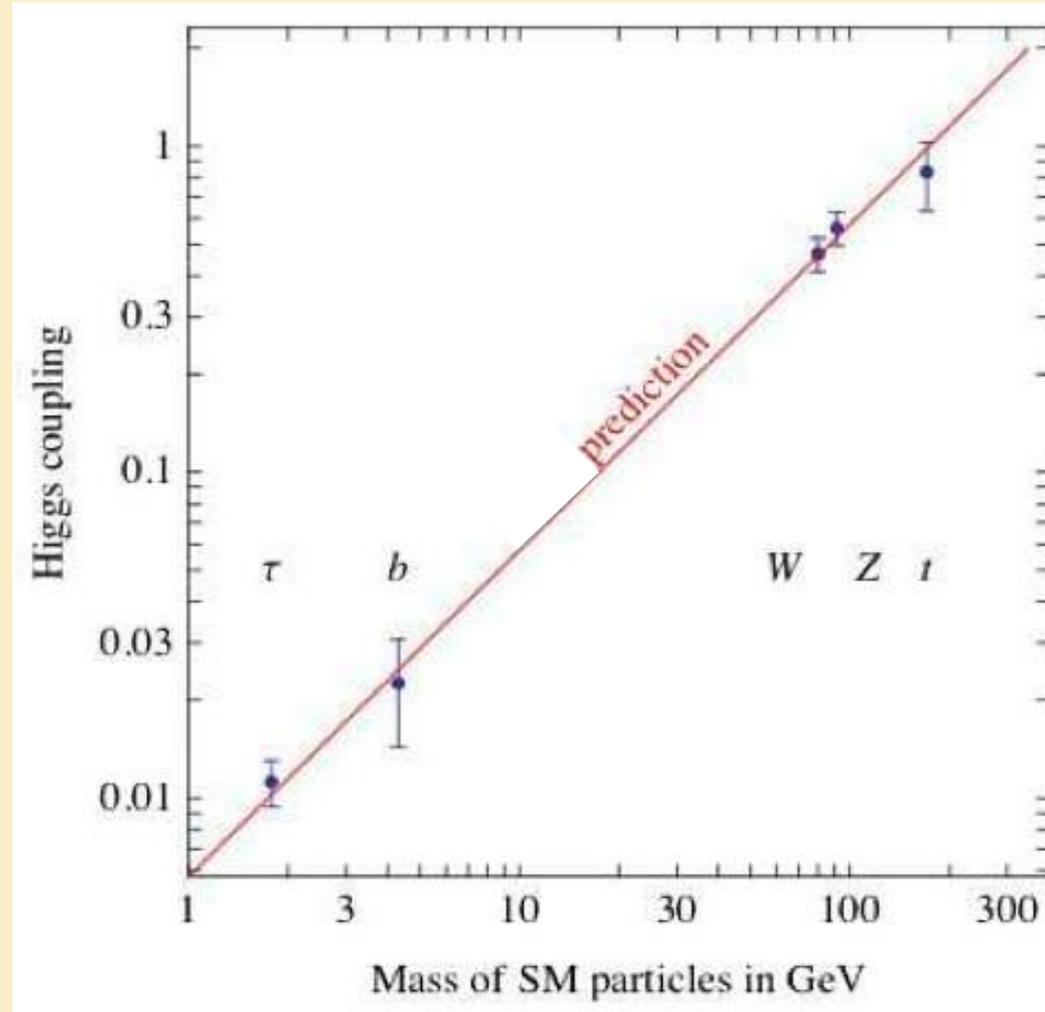
**The Higgs field gives mass without  
dissipating energy**

# How much mass?

The more a particle interacts with the Higgs field, the more mass it gets



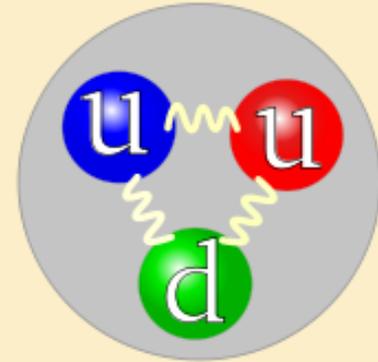
photon



# The mass in matter

# Quarks mass: 11 MeV

# Proton mass: 938 MeV



**99% of the proton mass comes from the binding energy given by the gluons**

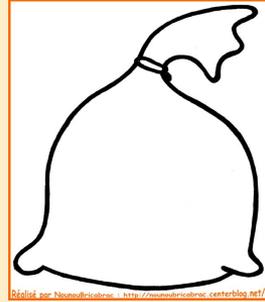


# To summarize, there are 3 aspects:

## 1. A mathematical tool:

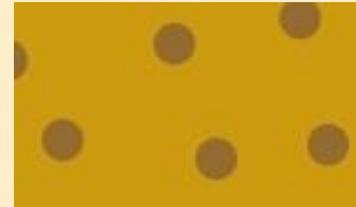
The Brout-Englert-Higgs mechanism:

$Z^0$  and  $W^\pm$  get a mass but not photons



## 2. A physical entity:

The Higgs field filled all space shortly after the Big Bang



## 3. An excitation of the field:

The Higgs boson



### 3. The Higgs boson

The Higgs field → the surface of the ocean

The Higgs boson → a wave



Waves are excitations of the ocean surface

We can create Higgs bosons by exciting the Higgs field

# How can we create a Higgs boson?

We need to concentrate a huge amount of energy in a small point in space – that's the role of the LHC



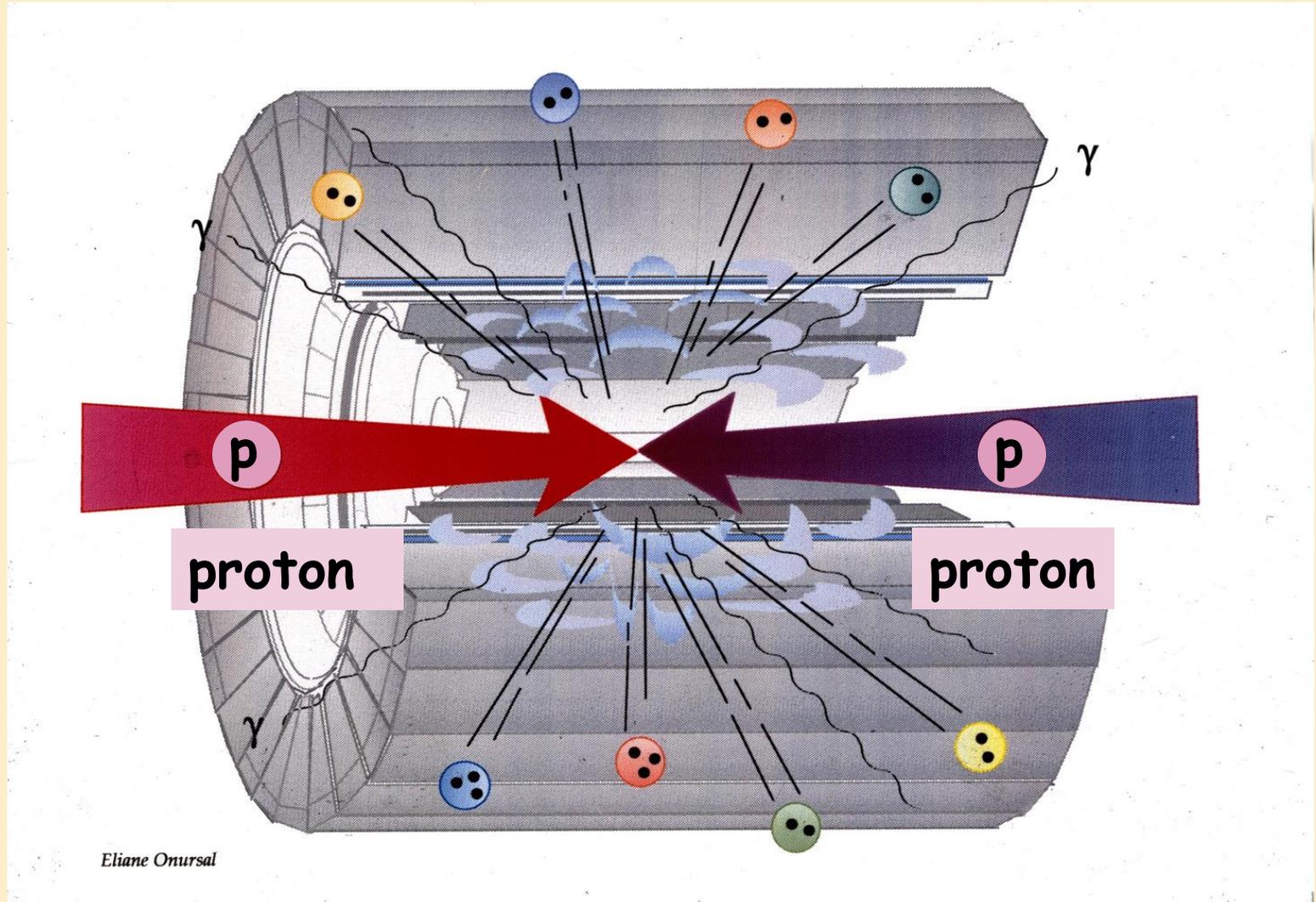
# The Large Hadron Collider (LHC)



Pauline Gaçon

The energy released during the collisions  
materialises to create particles:

$$E=mc^2$$



# Decay of a Higgs boson



Higgs



Z boson + Z boson



muon + muon + muon + muon

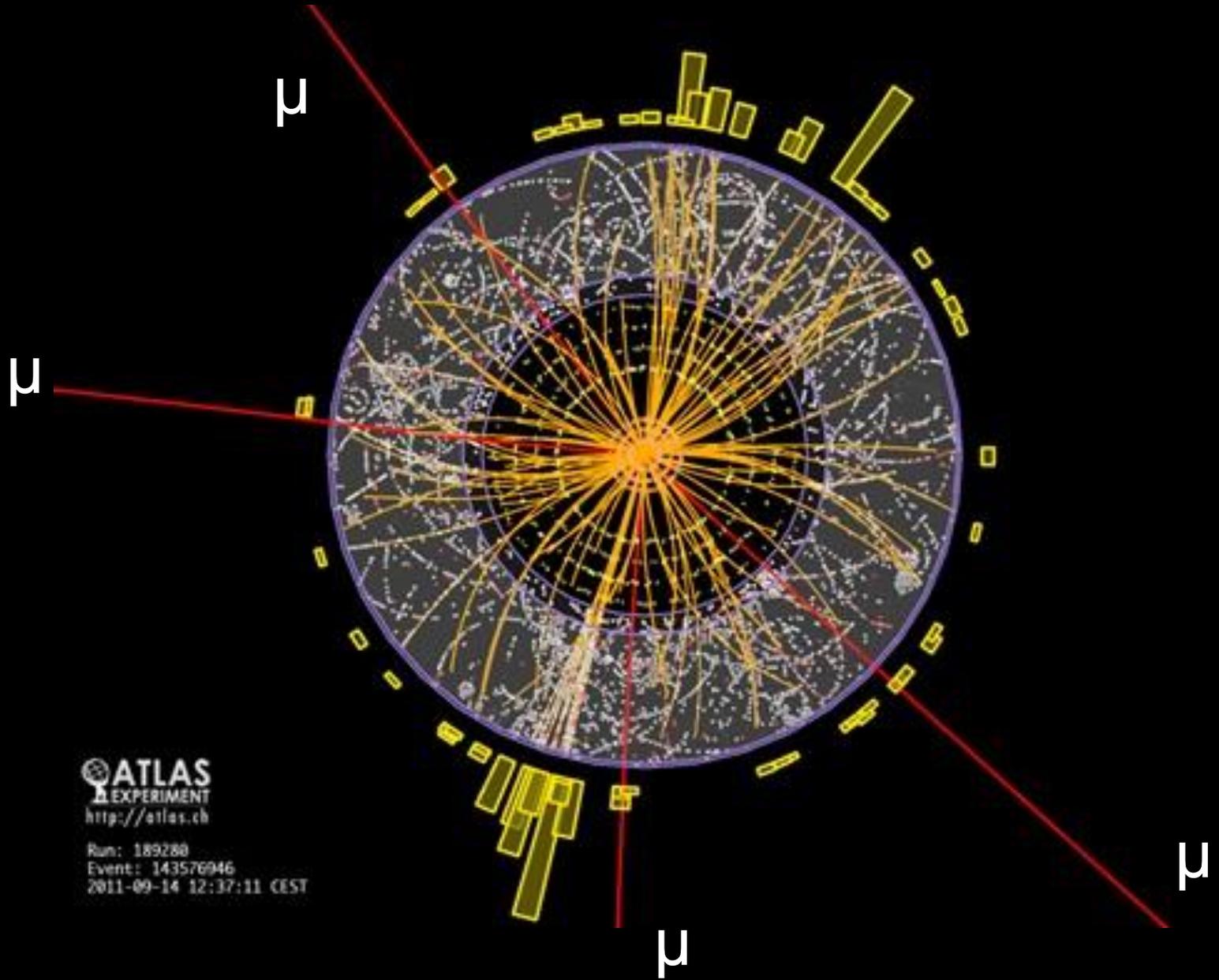


Z boson + Z boson



muon + muon + muon + muon

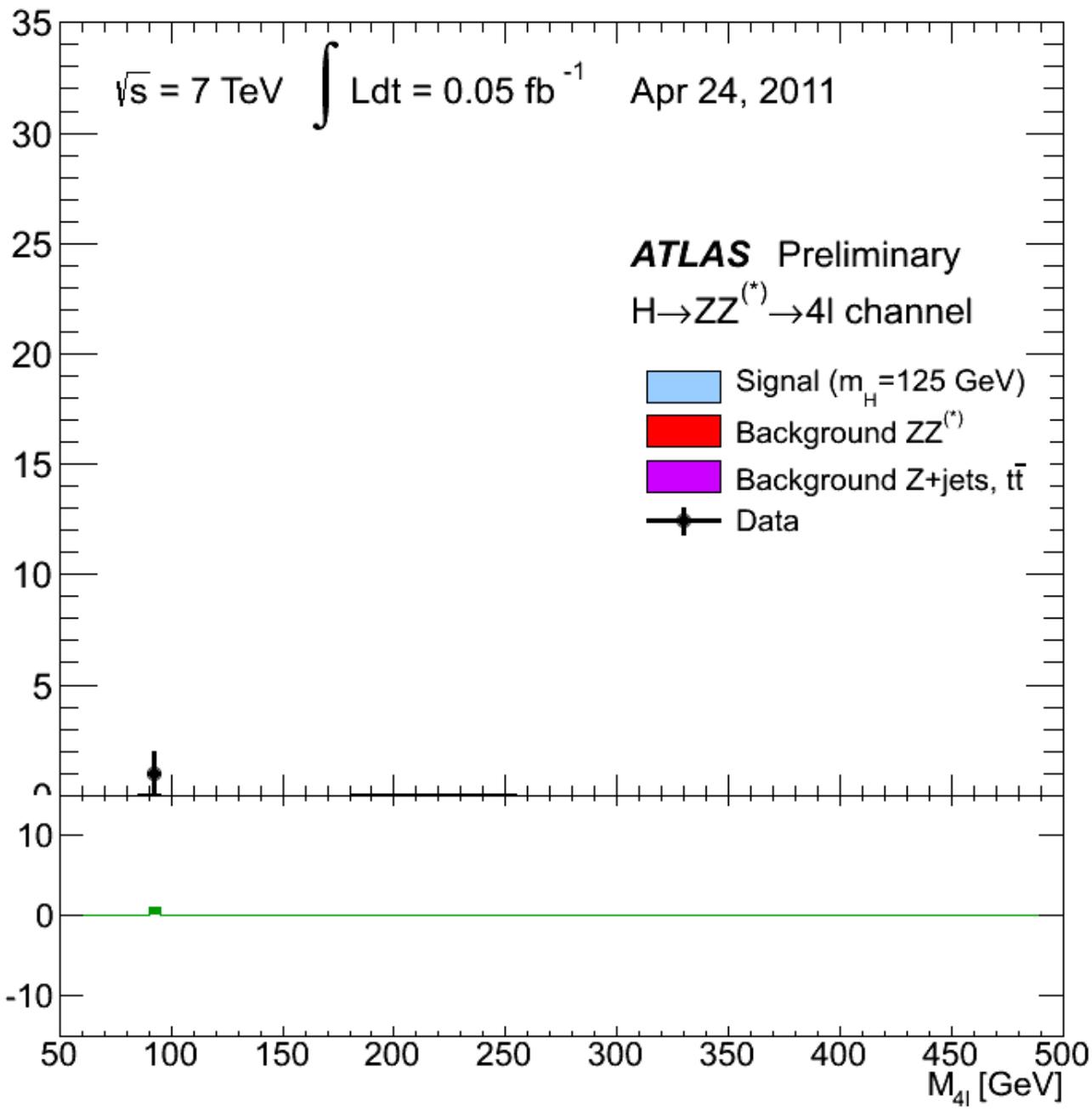
$H \rightarrow ZZ$  or  $ZZ$  ? Each  $Z \rightarrow \mu\mu$



**ATLAS**  
EXPERIMENT  
<http://atlas.ch>

Run: 189280  
Event: 143576946  
2011-09-14 12:37:11 CEST

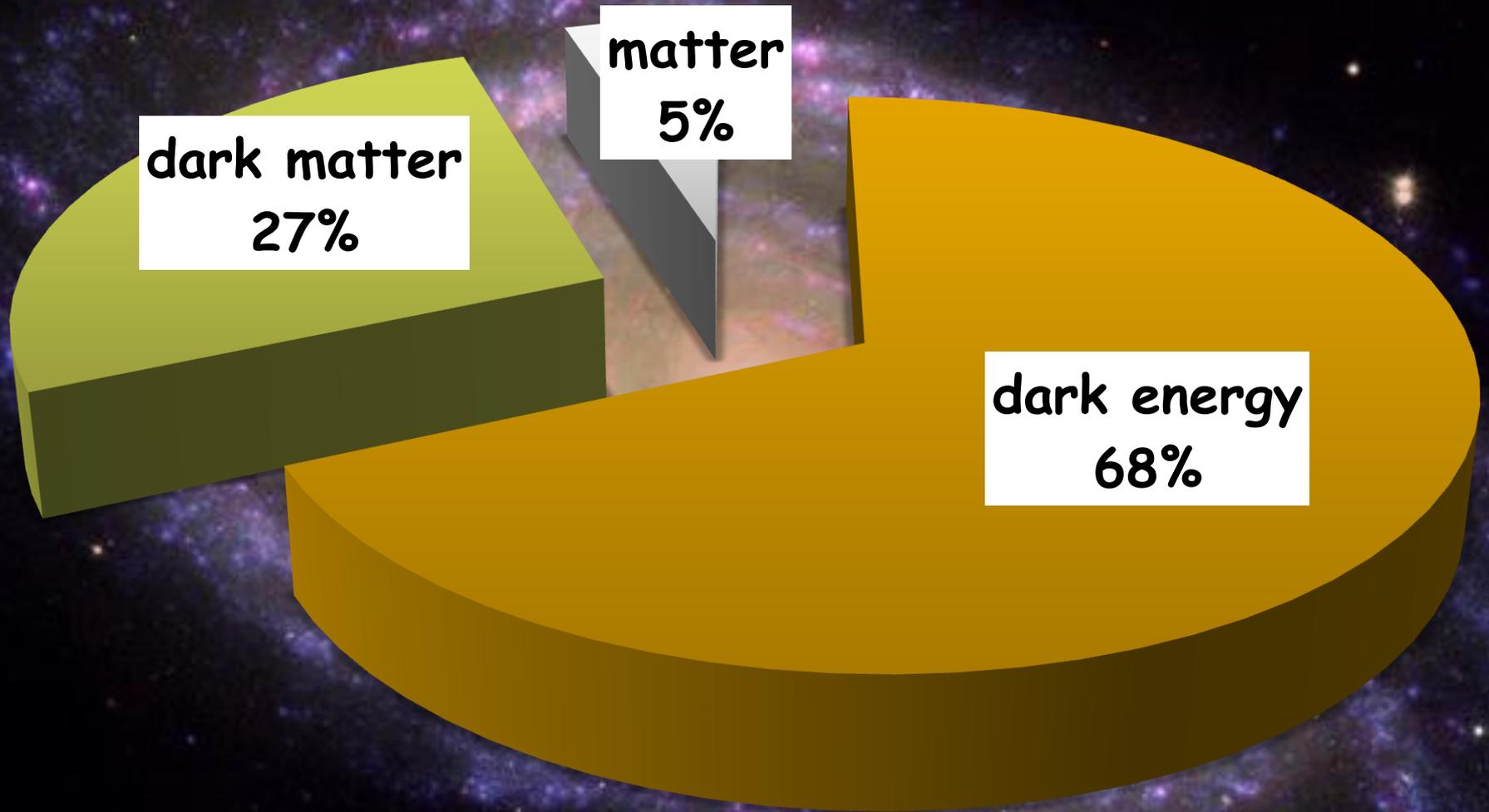
Events / 5 GeV



Data - Background

$M_{4l}$  [GeV]

# Dark matter mystery





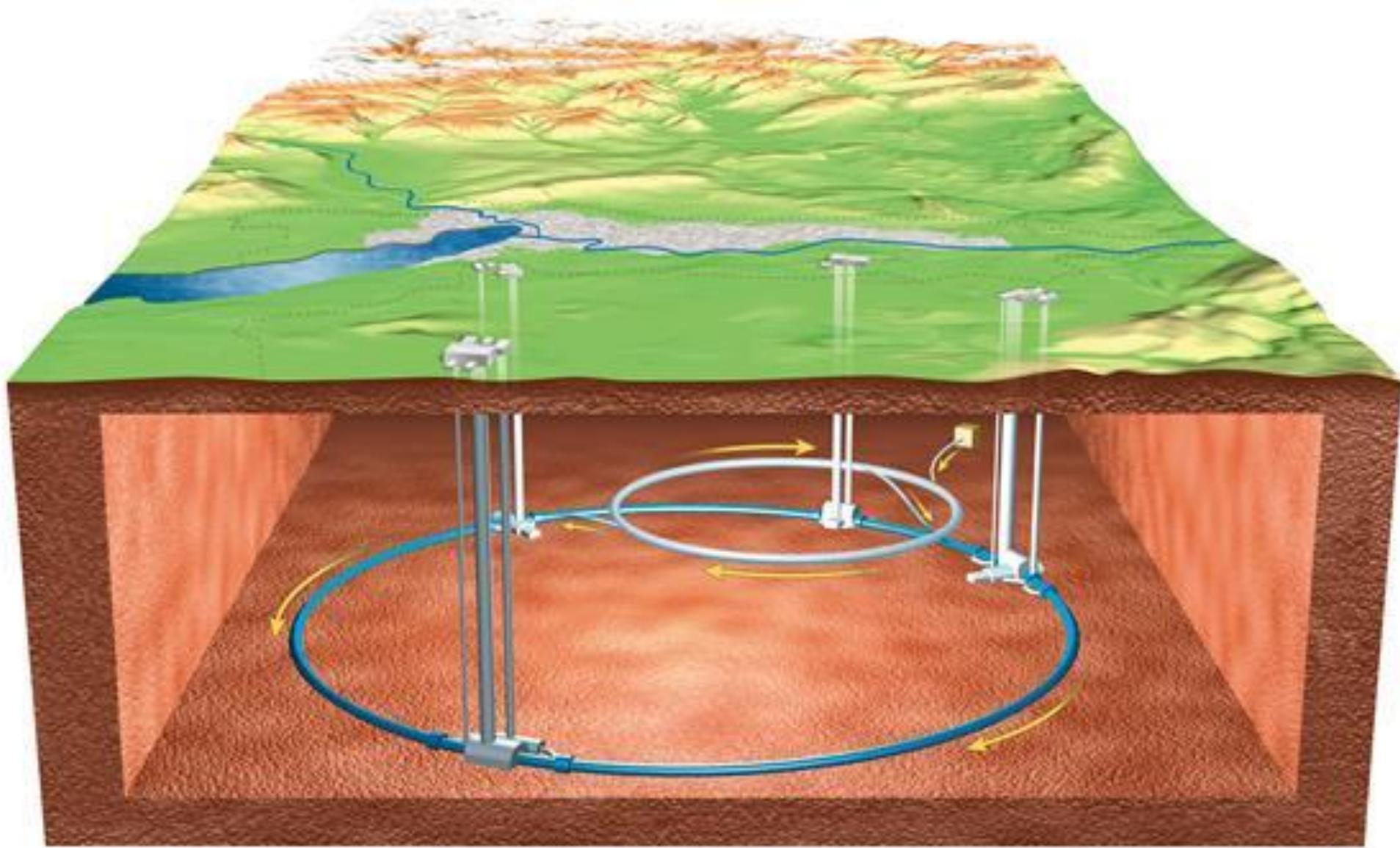
# Thank you for your visit



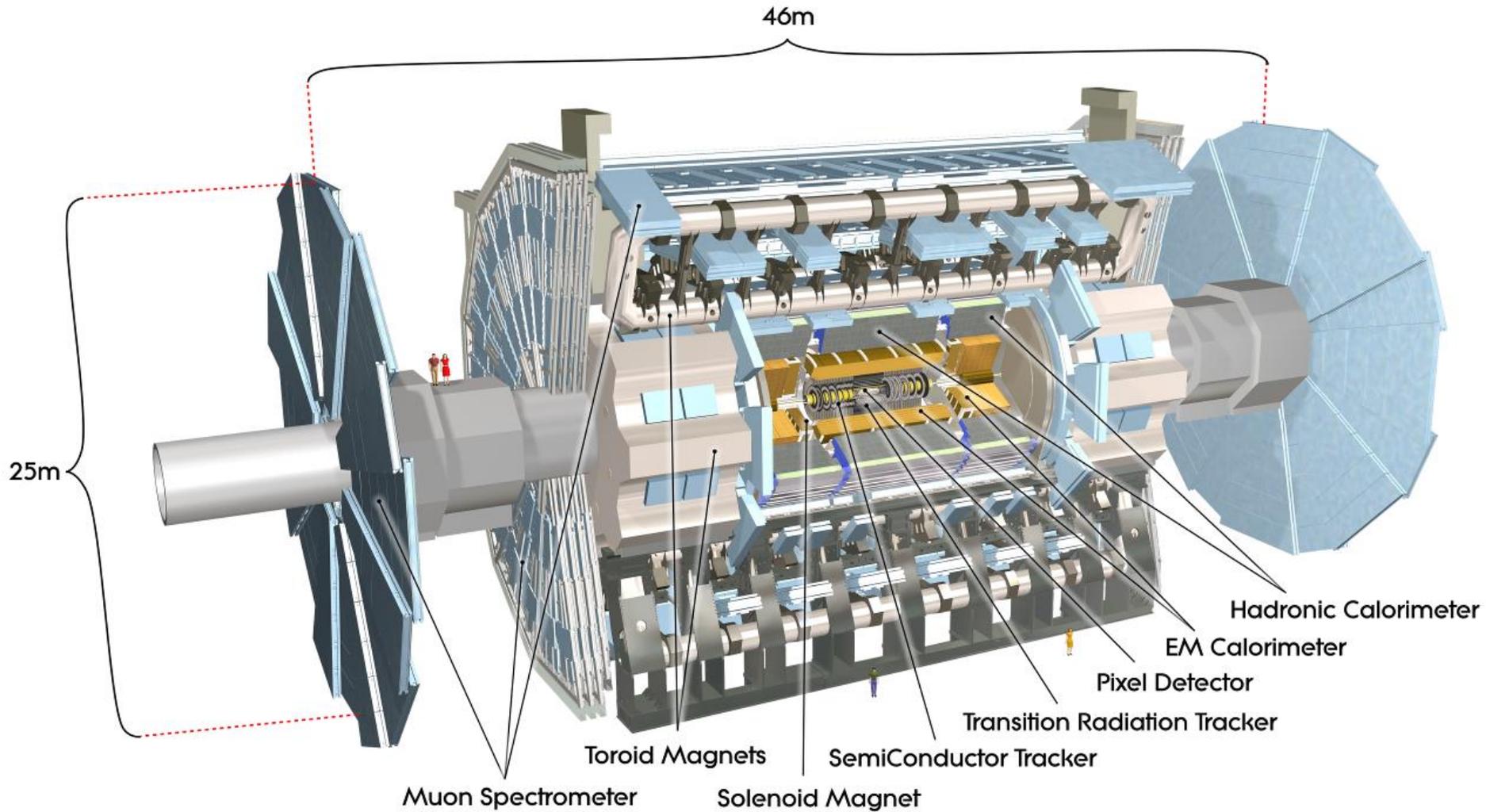
**Blogs on Quantum Diaries**

[Pauline.Gagnon@cern.ch](mailto:Pauline.Gagnon@cern.ch)

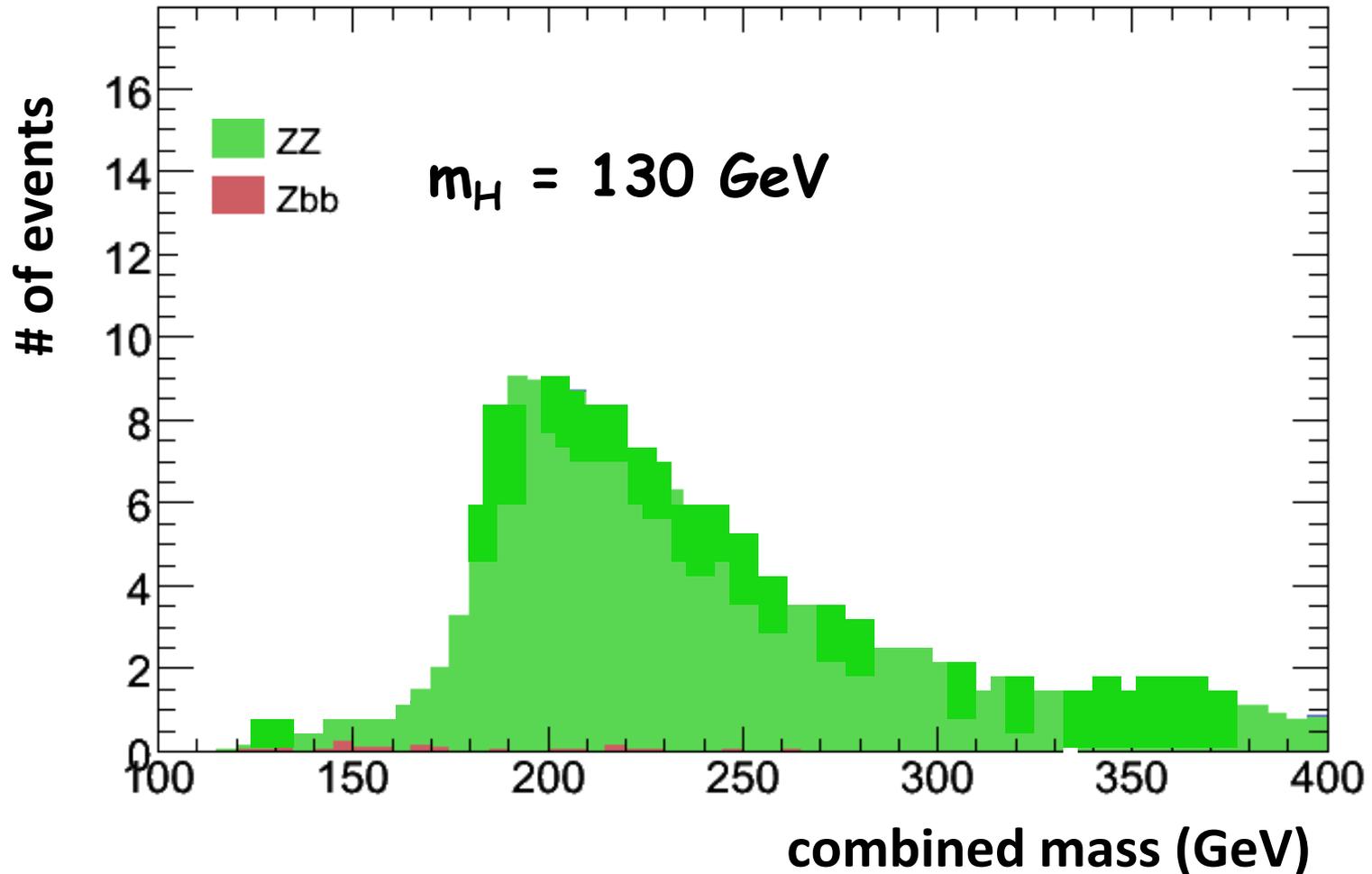




# The ATLAS detector: a giant camera



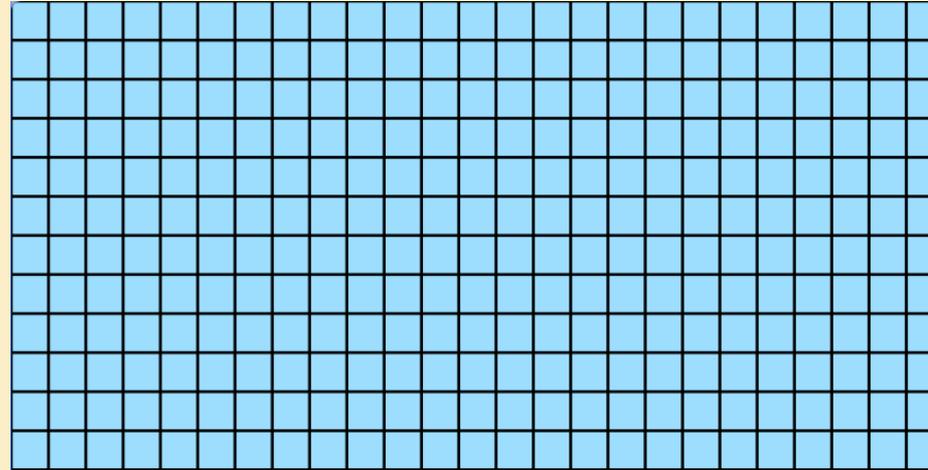
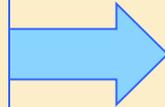
# How to distinguish an event containing a Higgs boson from all other events?



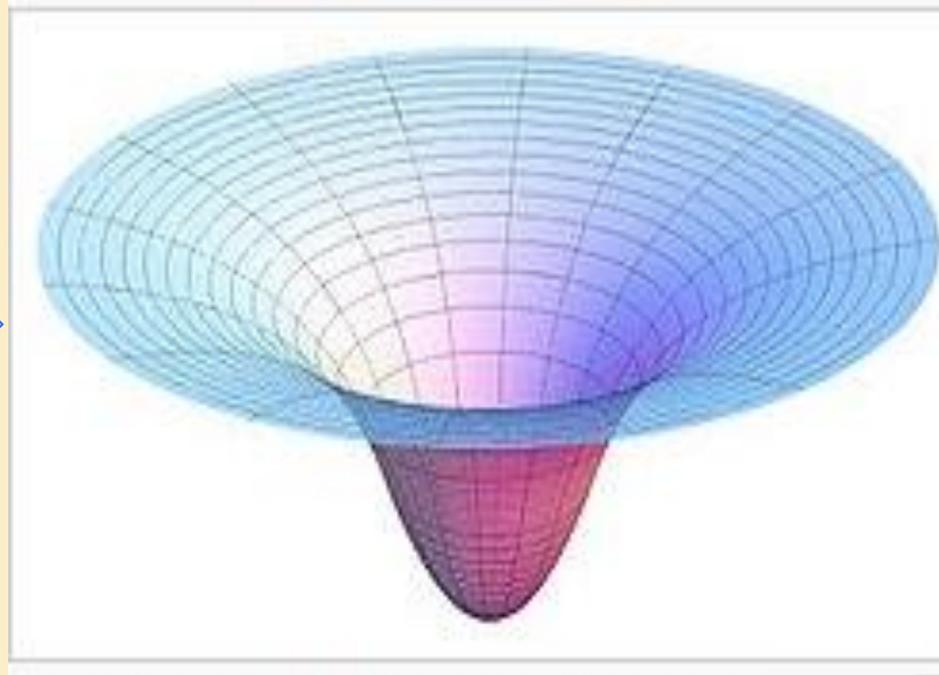
# Example: The gravitational field

In empty space:

- space-time is uniform
- light travels on a straight line



We do not see the gravitational field but it affects everything, including light, passing near by



# Great discovery

- # Without the Brout-Englert-Higgs mechanism, there was no way to explain the origin of mass
- # Without the Higgs mechanism, particles would travel at the speed of light
- # There would be no atoms
- # We now have a theory that explains nearly everything

